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APPLICATION OF PHOTOVOLTAICS TO EFFLUENT MONITORING

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Preface

Intended purpose

This report summarizes the work performed on the development project called PhotoVoltaic Remote Effluent Monitoring Systems (PV-REMS). The project consisted of several tasks with the overall purpose of evaluating the applicability of Photovoltaic powered systems to ZENON's environmental projects.

Scope of the Work

The work culminated in the integration and testing of a prototype data acquisition system which formed the basis of a general purpose system for remote industrial effluent monitoring.

Significance of the Work

The project is significant for ZENON in that it has made the company aware of the potential for photovoltaic (PV) powered systems as part of its product line, and also provided the design experience necessary to apply PV systems to other areas within ZENON.

Intended Audience for the Report

This report is intended solely for official use by EMR to evaluate the success of the work which was primarily funded by the Government of Canada. It can be used as a basis for follow-on work, especially in the area of commercialization of the technology.

Cautions

The prototype system described herein forms only the most elementary of platforms for effluent monitoring. There is much work to do to make the system really functional and useful. It would be very easy to overestimate the commercial importance of the potential product and therefore incur significant disappointment and costs later. It is strongly recommended that one proceed cautiously, building on this work incrementally and setting achievable goals at each stage.

Abstract

The development of a prototype photovoltaic powered, computer based, data acquisition and telemetry system is described. The system is configured to monitor industrial effluent streams, but could be used with any sensor assembly that provides data through an RS-232 compatible interface. The system uses the cellular phone network to transfer accumulated data from the sampling site to a base station where the data is automatically and regularly posted to unique files on a regular programmable predetermined basis. the sampling and transfer frequencies are individually adjustable. In addition alarm limits may be set to cause the system to call the base station or other predetermined number immediately that an abnormal condition is detected. The system can also trigger the collection of a physical sample through a standard multi-container sampler.

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1. Executive Summary — Résumé

1.1. English Summary

The PV-REMS[1] project was initiated via a solicited ZENON proposal issued in February, 1987. As a shared cost development project supported by the Renewable Energy Branch of EMR, it provided an opportunity for ZENON to acquire know-how in the application of photovoltaic power systems to an important aspect of ZENON's work. That aspect is the possibility of cost effective, real time, remote monitoring and reporting of various characteristics of industrial effluent streams. This idea has the potential to greatly reduce the cost and increase the effectiveness of pollution control mechanisms in many areas of the world.

The project was initiated in July 1987 and was completed in March 1989. About $130K of resources were expended, of which EMR provided about $88K. The work entailed the design, construction and testing of a prototype solar powered data acquisition and telemetry system intended for field installation at a sewer outfall, or elsewhere along an industrial drainage system. In addition to the photovoltaic based power supply, the system included a prepackaged sensor sonde and cellular phone based data transmission system.

During the development of the prototype, several challenges were faced and overcome. These included problems with cellular phone technology, the usual problems with software design and testing of small computer systems, and project difficulties as a result of staff changes and illness. The net was a delay in the project completion from July 1988 to March 1989, and somewhat reduced project goals. Once the technical and staffing problems had been resolved, the final construction and testing of the system went very smoothly.

The system performed flawlessly during its environmental testing in March 1989 and provides a sound basis for continued development toward commercialization of a PV-REMS based product line. There are many possible markets where PV-REMS might be applied in addition to the Ontario based MISA monitoring application, which is of current great concern for most industry in the Province. Section 6 of this report indicates the approach to capitalizing on the success so far by following through with its commercialization.

PV-REMS has provided an excellent vehicle for technology acquisition. The awareness of the potential for PV powered systems is now not only an intellectual idea in the minds of engineers at ZENON, but the prototype system is physical proof of its viability. In addition, the prototype may be applied in support of some of ZENON's field programs and further prove its value.

[1] PhotoVoltaic Powered Remote Effluent Monitoring System

1.2. Résumé

Le projet "PV-REMS[2]" a été entrepris par la Société ZENON en fevrier 1987, en collaboration et en coût partagé avec la branche "énergie renouvelable" de EMR. Il a permis de progresser dans la maitrise de l'utilisation de l'énergie photovoltaïque pour la surveillance de l'Environnement et a donné à ZENON l'occasion d'améliorer son "savoir faire" dans un aspect important de son activité: la surveillance à distance et la transmission en temps réel dans des conditions économiques satisfaisantes, de données caractéristiques d'un éffluent industriel.

Ce principe a de nombreuses applications et peut faciliter le contrôle d'un grand nombre de pollutions à travers le monde.

Le projet n'a réellement commencé qu'en juillet 1987 et s'est terminé en mars 1989. Environ $130K ont été dépensés, dont $88K en provenance de EMR. Le travail a compris la conception, le contruction et l'évaluation d'un protoype d'acquisition de données et d'un système de télémetrie alimenté en énergie solaire. Cette unité devait être installée au point de rejet, dans un êgout ou au long d'un reseau de drainage. En plus de l'alimentation par cellule photovoltaïque, le système comprenait un capteur et un téléphone cellulaire pour la transmission de l'information. Au cours du développement du prototype, plusieurs problèmes durent être résolus. Parmi ceux-ci figurent surtout des problèmes avec le téléphone cellulaire, les problèmes habituellement recontrés dans la conception des logiciels pour des petits sytèmes infomatiques et des problèmes inhérents aux absence du personnel responsable des essais. Cela se traduisit par un retard dans la réalisation du projet de plus de huit mois -de juillet '88 à march '89 - et par une limitation des objectifs.

Une fois les problèmes techniques et humains résolus, la construction finale et l'évaluation du matériel se sont néanmoins déroulées dans des conditions trés satisfaisantes.

Le système a fonctionné sans faille, à partir de son installation sur le site en mars '89 et a fourni ainsi une base solide pour le developpement final et la commercialisation d'un produit "PV-REMS". Il éxiste de nombreux marchés potentiels pour de tels systèmes et en particulier le programme MISA de surveillance des rejets industriels de l'Ontario. La Section 6 du rapport décrit l'approche qu'il nous parait bon de suivre, pout tirer parti de cette première évaluation et déboucher ainsi sur un produit commercial.

Le prototype réalisé par ZENON servira certainement à d'autres essais sur site, mais au-delà de lui, c'est la prise de conscience du potentiel des systèmes alimentés par des cellules photovoltaïques, qui constitue probablement la retombée la plus importante de cette étude.

[2] Système de Surveillance d'un Effluent, aliment par cellule Photovoltaïque.

2. Introduction/Background

In late 1986 ZENON was approached by Energy Mines and Resources Canada to examine ways in which ZENON might use Photovoltaic power systems in some of its products or projects. Several ideas were discussed internally and resulted in the ZENON proposal Application of Photovoltaics to Effluent Monitoring (February 16th, 1987). Acceptance of that proposal by EMR led to the PV-REMS project.

ZENON has been heavily involved in the sampling, analysis and treatment of wastewaters since the company's beginnings in 1981. As the size and capability of ZENON has increased over the years, its degree of involvement has broadened to most aspects of waste handling. In the past four years this involvement has included working with companies to pinpoint the source of pollutants and, if necessary, assist with site remediation in conjunction with consultants, Provincial and Federal Agencies.

ZENON has a continuing interest in developing the ability to monitor, on site, potential sources of serious pollution and alert the company and provincial authorities before the discharge has reached a serious state (i.e. the St Clair River PCE spill of 1986). Although ZENON has developed instruments to measure both inorganic and organic contaminants, these have been primarily designed for in-process applications where power consumption is of less concern. With the introduction of the MISA (Municipal and Industrial Strategy for Abatement) program in Ontario and rapidly growing concern across Canada regarding the control and containment of hazardous materials and toxic pollutants, it is timely to develop a remote low powered environmental monitoring system.

This project would have to be considered basic research and development. If the test system were to completely meet the criteria for performance, there would still be a good deal of development effort required to make it cost effective enough to install widely. This continued development should be handled as a separate follow-on project.

3. Objectives

- The ***objectives*** of the project were threefold:

1) Determine a suitable configuration of Photovoltaic (PV) modules for use as part of an effluent monitoring system, and evaluate its performance independently at a selected test site.

2) Given the constraints of the selected PV power supply, adapt and redesign ZENON process monitoring sensors to work within these constraints. The sensor suite was to include temperature, flow, pH, conductivity, organics (volatile and extractable).

3) Integrate the PV power system, the ZENON sensor suite and a commercial low power data transmitter, and evaluate the performance of the system at a selected test site.

- The ***status*** at project end was to be categorized in three ways:—

1) HARDWARE: ZENON would possess a working bread-board system for remote monitoring of effluent wastes. (The system would be usable in carefully controlled circumstances, but would not be suitable for typical engineering field work.)

2) KNOW-HOW: ZENON would have an reasonable knowledge base regarding the operational problems of PV systems at industrial sites.

3) PLANNING: ZENON would be in a position to prepare a detailed plan for commercialization of PV-REMS. (See Section 6)

- The expected ***benefits*** to EMR included:—

1) Enhanced use of PV in the waste management field– a critical issue in the Energy Sector;

2) Good potential for future licensing of a portion of the developed technology;

3) Increased industrial exposure to PV systems.

- Expected ***follow-on activities***, on the basis that the project was successful, included:—

1) Formal market survey for a potential product based on the specifications of the field prototype.

2) Based on the results of the market survey and the cost estimates for commercialization, a decision would be made to develop the technology in the appropriate manner.

4. Description of the Work Performed

This section describes the original proposed approach and methodology to meet the objectives as indicated in the proposal. *Text in italics describes what actually happened, the degree of success obtained, and any major difficulties encountered.*

4.1. TASK 1 Determine a suitable configuration of PV/Batteries

4.1.1. PV Power Supply Specification

Assess Power Requirements: Analyze the anticipated power requirements, and duty cycles for each of the elements of the proposed effluent monitoring system (PV-REMS). Integrate these needs with the expected operational cycle in the field and the known climatic conditions for the test site area.

This power requirements assessment was done, and later proven to be very conservative. The power consumption estimates for the computer, sensor package and transmitter were are all overestimated.

Model the Performance: Various configurations of PV and batteries will be modeled in conjunction with Ontario Research Foundation using the software recently developed by them.

This sub task was eliminated because of the small size of the system and the non-critical nature of the prototype operation. This approach would have be suitable for a larger, more complex system.

Detail the Requirements of the PV: List the needs resulting from this analysis and produce a working specification. Include test site considerations, especially environmental conditions.

This task was somewhat overstated, since most vendors provided fixed configurations of standard PV products. The procurement would amount to choosing the package which conservatively met, but did not grossly exceed the anticipated needs of the system.

4.1.2. Procure PV Components

Source PV panels and Batteries: Investigate potential suppliers of PV panels and batteries by direct contact and through other known users of PV/battery systems. (Such as the Canadian Coast Guard, Water Survey of Canada, and TPK Solar Systems)

Several vendors and other sources were contacted including Dick Terzi of Water Survey of Canada, TPK, Lenbrook, SolarPak, and others.

Issue Specification: Get quotations and buy two suitable sets of components. (One for use at ZENON, probably roof mounted, and a second for field installation.)

In fact only one set of hardware was purchased. The components were less expensive than expected and readily available from the supplier should problems arise.

4.1.3. Evaluation

Assemble and Test: Using a suitable load simulator, evaluate the performance of the PV power sub-system in the lab, under a variety of temperature and humidity conditions.

Some functional lab testing was done, but the current output from the panel was limited under indoor conditions and precluded full functional tests. It did not seem worthwhile to set up elaborate simulators when the product was well specified and seemed to met specifications according to simple test results.

Modify as Required: Make any changes which are required and amend specification if necessary. Prepare the field test unit. Select a suitable field test site from those plants currently working with ZENON.

The power system was simpler than originally anticipated; therefore, this task was unnecessary.

Install on Site: Install and monitor the operation of the power subsystem over a period of four to six months, preferably through the winter months.

The PV panel was mounted on the roof of ZENON and tested from November 1987 to April 1988. It survived and retained 100% functionality.

Assess Results: Recover the test unit and inspect for damage, deterioration and any other effects which might impair the operation of the complete PV-REMS. Analyze operational data.

The PV Panel survived the winter. There was no reason for concern.

4.2. TASK 2 Redesign and Modify ZENON Sensors

4.2.1. Low Power Organics Monitor

Redesign Electronics: Reduce the power requirements of the light source; replace the microprocessor with a CMOS substitute and implement a sleep mode; review the design of all analog circuitry and trim loads as much as possible in keeping with the need for accuracy. Modify the sample cell to accommodate the higher organics levels and the need for mounting in a sewer pipe.

At the time the proposal was written, it was assumed that the ZENON Organics Monitor (ZOM) would be in production, and merely need conversion to lower power electronics to serve in PV-REMS. Unfortunately, priorities changed and ZOM was not fully engineered. Although a U.S. Patent issued in 1988 (No. 4,775,794 issued October 4, 1988), no further work was done. It was therefore impractical to adapt the unit to PV-REMS.

To handle volatile organics, search for candidate sensing technologies, acquire and integrate.

Sniffer cells were acquired for this purpose, but no further work was done on this task as result of other project priorities mentioned below.

4.2.2. Standard Sensors

Sensor Adaptation: Modify available sensors for pH, temperature, conductivity and flow and electronics to allow integration into the PV-REMS.

Although separate sensors and custom packaging were seriously considered, the option of acquiring a prepackaged set of sensors was also included. In the end, a standard package from Hydrolab called "SCOUT" was selected. This unit provided a basic set of probes including temperature, pH, conductivity and dissolved oxygen. The microprocessor based unit also included calculated parameters for % saturation and salinity. Flow was always a serious measurement problem and very site specific. The simplest way of dealing with the problem, had the system been used at an actual field site would have been to measure water depth and roughly estimated the flow based on head.

4.2.3. Evaluation

In House Testing: Test the modified sensors in accordance with the expected field conditions and the power variations which are anticipated due the PV power subsystem.

The detailed approach to testing described here was not required, since a standard commercial sensor package was used.

4.3. TASK 3 Integration and Testing of the PV-REMS

4.3.1. Data Logger and Transmitter

Evaluate Hardware: Source, select and procure a suitable data logger and transmitter/receiver system, in keeping with the other needs and limitations of the PV-REMS.

This task became one of the major challenges of the project. The decision was made early in the project to use the cellular phone system to handle the data transmission. There was no doubt that the cellular phone was the correct long term choice in terms of availability, cost, range, etc. The only real problem was that automatic data handling via the cellular network was a limited, oversold, capability. To complicate things further, there was a law suit in process over the rights to manufacture cellular modems. Furthermore, in spite of clear instructions, vendors could not seem to understand that there would be no one available to dial the central monitoring site number. A Mobira phone was ordered and delivered on the understanding that the data interface included "autodial" capability, but when the phone was received, it was clearly stated in the manual for the data interface that such a capability was simply not supported!

Finally through technical cooperation with CANTEL, a Morrison and Beatty modem and phone interface for a Panasonic phone are obtained. This unit provided all the functions necessary for use by PV-REMS.

Since data logging was split between the microcomputer in the sensor and the data handling microcomputer there was considerable flexibility in how data was collected and stored.

4.3.2. Completed Field Prototype

Assemble a complete PV-REMS: including the PV/battery power subsystem, sensor suite and transmitter. Several channels will be dedicated to diagnostic monitoring of the PV subsystem and power consumption within the sensors themselves. Perform functional tests, and modify as required.

The physical assembly of the system was fairly straightforward. The complexity was in the design and coding of the software. There were no serious complications in the hardware and it worked reliably from the beginning.

Set up data logger alarm system on IBM PC or Macintosh.

The collection of the data from the PV-REMS consisted of leaving a Macintosh computer and modem monitoring the phone and set up running a terminal emulator program, "Red Ryder 10.3", in "Host" mode for automatic data capture.

4.3.3. Field Test Evaluation.

Install PV-REMS at Field Site: Monitor the performance of the system, placing particular emphasis effects of the PV subsystem. The test period should be at least six months. Grab samples will be taken at regular intervals and analyzed in the laboratory to confirm the validity of the field measurements.

Due to delays in scheduling and software problems, it was not possible to put the system in the field in the manner originally envisioned. On the other hand, the system performed so flawlessly during its exposure on ZENON's roof (from March 5th, 1989), that the designers are confident it could be used at other sites with minimal problems.

The sensor assembly was immersed in an aqueous solution in a bucket in the utility room underneath the roof hatch.The test solution was altered randomly in a single blind manner to ensure that the system could detect changes in pH, conductivity, etc. Of course such checks were primarily dependent on the sensor package and not so much on the PV-REMS data collection software.

Recover the PV-REMS: Evaluate the performance of the PV-REMS and check the condition of the system both physically and electrically.

At time of writing PV-REMS is still operating on the roof. As of March 28th, the PV panel was disconnected to test the battery capacity of the system.. It is expected that the system will operate for at least a week before the battery drops to 10 volts, the voltage at which the system ceases to try to call the home base.

Write Final Project Report: This report will summarize the findings of the development project and make recommendations regarding the suitability of PV for future application within the company, and comment on the commercial feasibility of the PV-REMS.

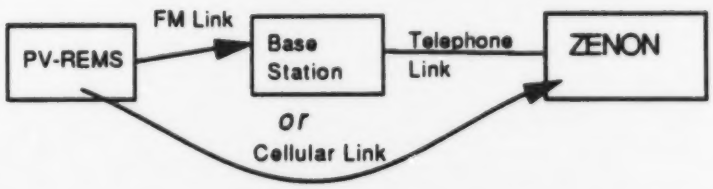
As stated elsewhere in this report, this technology is definitely applicable to a range of monitoring applications. The market is limited by the selling price and the number of situations where AC power is not readily available.

This completes the description of the project by task, except for the agreed additional task — The commercialization plan— which is documented in Section 6.

4.4. Design Issues

The major design issues were the choice of telemetry method, selection of sensors and computer system. The choice of PV system was straightforward and economical. This, in itself, was a major revelation to the designers, in that they had expected the PV aspects of the project to be more complicated and expensive. These facts combined with the proven reliability of the PV subsystem ensure that the use of PV power will be considered often during future design cycles at ZENON.

The original idea of using FM links to base station and telephone relay to ZENON was abandoned early in favour of the cellular phone system.



Since the telephone system would be used anyway, why not eliminate the complexity of the base station and call directly to ZENON from the PV-REMS. Such an approach greatly simplifies the field installation. It may be that the capital cost is somewhat higher, although the costs of the FM approach were never evaluated in detail, but the convenience would seem to override additional cost, if any. The one major disadvantage of the cellular system is that is does not provide universal coverage, however, it does provide coverage of nearly all industrial areas and therefore nearly all sources of pollution[3]

[3] This applies to other countries as well as Canada. In a recent trade mission to the People's Republic of China it was noted that there is a cellular phone system in place in Shenyang —a large primary industrial centre and one of the ten most polluted cities on earth.

4.5. Project Evolution

As the project evolved, it became apparent that there would be challenges associated with the organic sensor, the cellular phone and finally organizational problems. As mentioned earlier, the organics monitor was not to be commercialized as expected, within the project time frame, thus eliminating a potentially valuable key to the direct monitoring of organic pollutants. The next hope was to try to make surrogate measurements, that is — find a correlation between changes in pH, conductivity and the pollutant of interest. So for example, it may be known that every time there is a spill of Xylene, there is also a process upset which affects the pH or that the Xylene leaches material from the drainage system which changes the conductivity of the water. Such evidence can be used to infer a possible Xylene spill and notify the base station or take a water sample. Thus it was determined that the sophisticated, and perhaps unreliable measurements would be replaced with simpler, more reliable ones. (The identification of this correlation remains an outstanding task in view of the shortened field test.)

The cellular phone posed a problem in that it was not originally part of the project design and was oversold on the part of cellular phone vendors. With the broad availability of cellular phones comes the "retail" salesman who sincerely believes the erroneous information (s)he conveys. It was simply hard to find people who know more than the kind of things your average real estate agent needs to know about cellular phones. When the R&D people at Cantel became seriously involved, there were still problems. For example a digital data service was to be offered by Cantel. It was to be accessed by the number "*nnn". Unfortunately the "service" came and went while we were trying to evaluate it. The current status of the service is unknown. Tracking down problems with the service simply consumed too much time.

Finally staffing problems followed the project. Shortly after beginning the work, ZENON reorganized and the assigned project engineer changed divisions, taking the project with him. That was okay until he changed jobs and left the project behind. There was some delay while the project was restarted and then the project manager became ill for about two months. This would not normally have been a problem, except that the skills required to carry out the work were scarce and in heavy demand at ZENON. The obvious solution was to bring additional staff on board, but locating suitable candidates for Instrumentation R&D roles at ZENON has always been challenging and time consuming. Finally, Eric Bower was staffed in November, 1988. He was able to bring the pieces of the puzzle together in relatively short order and produced a working prototype.

The following excerpt from a letter to SSC and EMR dated May 5th, 1988, explains the evolution of the overall project goal:—

> "Other than the obvious impact of the delayed schedule, there is some impact technically. In view of the information obtained so far, it is necessary to change the emphasis of the project somewhat. We had hoped that our organics monitor technology would be in production by now, and therefore easily adapted to this project. However, there have been delays in that area. Secondly, although it is clear that the cellular phone is the technology of choice for Southern Ontario, there are subtle problems associated with adapting it to automatic remote use. Thirdly, the implementation of multi-tasking[4] on ZENON's single board micro has been delayed as a result of problems in the Masterforth operating system....
>
> "These three technical factors, plus staff changes persuade me to modify the project goals as follows:—
>
> *The modified objective of the project is to provide a PV powered data acquisition platform which is adaptable to a variety of water quality and quantity measuring sensors, and provides daily summaries of the measured parameters to a central base. In addition, in response to user programmable alarm conditions, the unit will issue an alarm to a predetermined phone number, and/or collect a sample for lab analysis.*
>
> Although the scope of the work is somewhat reduced, the delayed schedule will permit the testing of the complete prototype system during the most challenging time of the year for PV systems, i.e. November."

With the illness of the project manager in 1988 and delays in staffing, the prototype construction slipped into December and with software and integration problems, the field testing slipped from November, 1988 to March, 1989. The overall project slippage was 8.5 months.

The modified project goal as stated on the previous page was met and provides a good basis for future work.

[4] Multitasking would have been good to have in the system, but the current prototype operates in a simple sequential manner triggered by interrupt driven timers.

4.6. Final Prototype Design

The final prototype consists of a NEMA 4X (dust and water tight) cabinet containing a cellular phone and cellular modem, single board micro computer, interface electronics, and a battery. There is an externally mounted 40 Watt peak solar array and regulator, and a sensor sonde with 20 metres of cable. There are two connectors on the cabinet which allow access to the computer by an external terminal or PC, and an output contact closure which can be used to activate an optional sampler.

The software on the single board micro allows for the programming of alarm limits as well as sampling and reporting intervals. There is enough memory on board to store more than twenty-four sets of measurements.

The PV subsystem is apparently grossly over specified. On the coldest days during the testing, the battery regained full charge within a few hours of dawn.

The cellular phone, which is potentially the biggest power drain is automatically capable of minimizing its transmission power down to as low as 300 mW. The original CMOS ZENON single board computer, which was adapted for the project, was estimated to consume 90 mA while active, the NMI 68HC11 based board, which was substituted, used consumes only 10 mA. There again was a great power saving over budget. Finally the Scout sensor package is a very lower power unit, which consumes much less than the original power budget for the sensors. These facts combined with the fact that the phone is only active for one or two minutes per day suggest that a much smaller battery and panel could be used.

Specifications and much more detailed descriptions for all these system elements are given in the Appendix.

4.7. Prototype Assembly

The assembly of the system hardware was relatively straightforward once there was full time staff committed solely to the project. No serious problems were encountered. There is one outstanding issue in terms of the mounting of the system in the field. Several options are possible but are very site dependent. So a mounting scheme would have to be worked out for each site. In the worst case the components can be bolted to a fence or wall or simply set on the ground.

Similarly, the design of individual software elements were straightforward, even simple, but there was a fairly large volume of code to deal with including that for keeping track of a calendar and correcting possible error conditions in dialing and connecting to ZENON's host computer.

4.8. Integration and Functional Testing

Problems with debugging software prolonged this task by several weeks. The major problem which confused the issue was how the 68HC11 processor handled interrupts in the Forth language environment. Examples provided indicated that fairly sophisticated code could be run as interrupt routines, but this was suspicious in terms of normal coding practice. Sure enough when the interrupt service routines were cut back to handle the minimum updating functions, the software performed reliably. A second problem was lack of memory. This was tackled initially by "factoring" the code to reduce space requirements, eventually more memory was added. This in itself created as small problem in that the memory map for the computer was not contiguous. There were many other small problems that were fixed along the way, but the change in interrupt handling was the major problem that needed solving.

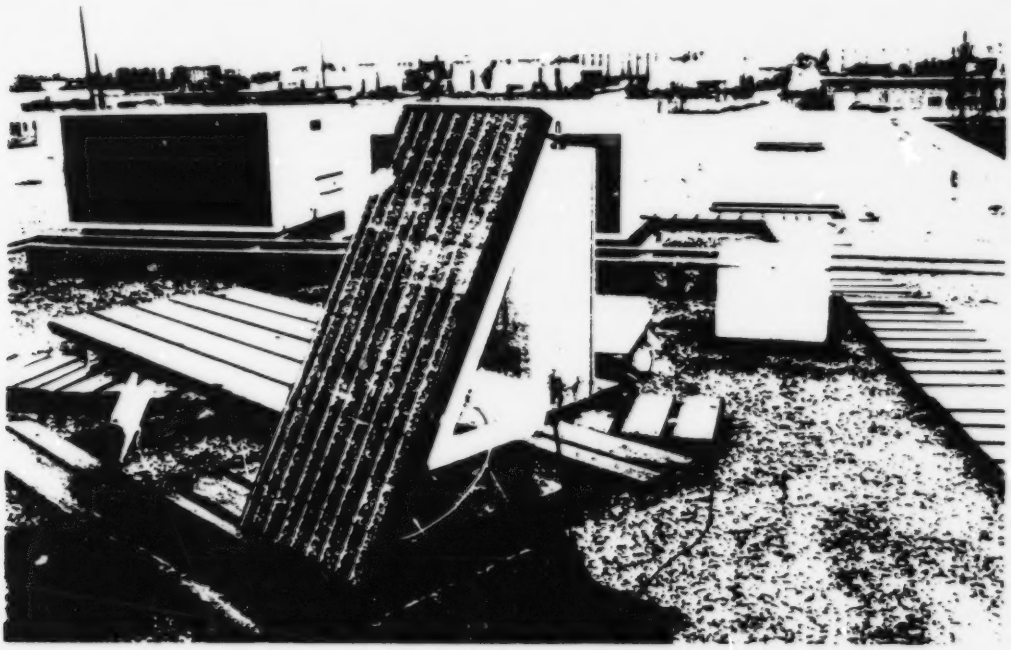
4.9. Operational Testing

With the rapid approach of the project end, the field testing of the unit was necessarily cut short. The final testing began on March 5th, 1989 on the roof of ZENON's building in Burlington, Ontario. The sensor sonde was placed in a bucket inside the building to keep it from freezing (It's tough to measure pollutants in frozen water) and various changes were made in pH and conductivity during the course of the testing. The key thing about the testing was the fact that there were some good storms in March, so that it was cold (≈ —15°C); dark (for a few days); and icy—there was a classic ice storm which provided a coating of ice several millimeters thick on everything.

The prototype has worked flawlessly during the trial. It even dealt well with the fact that someone had turned off the modem at ZENON so that the data collection computer was disabled. PV-REMS called every two minutes for over 6 hours until the modem was powered up. All the backlog of data was transferred, including that which was collected during the six hour delay. The system quickly recovered from this excessive power use.

The testing program did not measure up to that originally envisioned in the proposal, but that scenario also allowed for a few cycles of failure, repair and retest. The fact that the PV-REMS prototype has experienced no failures at all, suggests that it has more than passed the test and could be used with some confidence at a remote site. It is hoped that such an opportunity arises in the near future.

Photo of PV-REMS under field test conditions



5. Results

Actual data are given in the Appendix. This section is intended to provide a brief discussion of the results, focussing on the benefits of PV-REMS.

5.1. Discussion

5.1.1. Benefits of Photovoltaic Power Systems

The overwhelming conclusion about PV systems from this work is that they are much easier to use, more reliable and less expensive than had been imagined. For land based work where the system can be oriented in a fixed way, the few hundred dollars spent on PV parts would clearly provide a degree of dependability and independence which is unmatched by any other power scheme.

Absence of AC power source also simplified design since no CSA approvals were required. Due to the proximity of water to the unit, it is safer to use low voltage DC systems.

A smaller, lighter unit could be built (the size of a briefcase) for hand held work in the field.

5.1.2. Benefits and Problems with Cellular Phones

Together with solar power, the cellular phone provides unparalleled flexibility in terms of industrial data acquisition. The installation time on site is reduced to essentially zero (in a secure zone) and it is now possible to collect field data at home base as easily as though one were collecting data in the lab. The system can provide an alarm anywhere there is a phone, or even a beeper, within minutes of a spill or other abnormal condition.

The cost of high quality cellular phones may still be an issue, but prices have dropped over 40% during the course of the project and should be available at a significant discount should PV-REMS go into production.

To increase data reliability the data transfer mechanism should incorporate "X-modem" protocol or equivalent. Very few data errors were encountered using simple text file transmission, but it would be good to reduce the error rate to zero.

5.1.3. Sensors

The simple sensors are handled easily by packaged sondes, such as used for this prototype, but there is a lot of scope for new measurement techniques and sensors for field use. Of course, flow measurements will always be a problem due to the site specific requirements[5]. The issue of surrogate measurements is not resolved. Again it is likely to be a site and industry specific problem, requiring much effort.

[5] Different methods are required for open channel flow, filled pipe, effects of slurries, bubbles, oil & grease, etc.

6. Plan for Commercialization

To quote again from the original proposal,

> "The successful completion of this preliminary work will enable ZENON to evaluate the need for a commercial version of the system. It is unlikely that the prototype design itself will prove to be economical enough to be applied widely, but by the time it is built and tested, we should have developed some ideas which could lead to the necessary cost reduction. ...There is no doubt that given a suitably low cost, i.e. about $5-10K per system, there is potential for a few thousand installations in North America as pollution control efforts become stronger. This estimate is based on the number of large plants which are known to have spills of one sort or another each year. As well as benefiting the process industries, the PV-REMS would also get significant use in the energy sector."

To provide an indication of the next step, this section details a plan for commercialization of PV-REMS.

6.1. Possible Markets

PV-REMS could be applied anywhere there is access to the outdoors and access to the environment to be measured. If the cellular phone module is used, the zone of application is limited to the areas served by the cellular network, but that is a growing area and will probably increase to cover virtually anywhere PV-REMS might be applied usefully by the time the product is commercialized.

Access to these markets is limited by the unit cost on one hand and the availability and suitability of sensor modules. Where regulatory agencies are involved, there needs to be acceptance of the approach and specific methodology used by the system.

There are some obvious potential markets such as MISA monitoring. PV-REMS will never entirely replace the chemical sampling program now underway, but there is an increasing awareness of the cost and complexity of the current program. Alternatives will definitely be sought over the next few years. Basic parameters such as pH and conductivity are included and must be measured quickly (within 3 days of sampling) to be considered valid. If the surrogate concept could be sold, then several other parameters could be indirectly measured with very simple instruments. Other problems such as samples lost in shipment, complex data entry programs and broken sample bottles plague the current scheme. It will clearly be much easier, cheaper and more reliable to ship the results through the "ether".

6.2. Product Cost Objectives

The current factory cost for the unit would be approximately $15K, plus the sampler, R&D costs, royalties, etc. This translates to a selling price of $25K to $30K. For a company with four sampling streams, this $100K investment becomes significant, especially if additional sampling is still required. Clearly the factory cost of the unit must be reduced in order to expect any reasonable market size and penetration.

Table 6 –1 PV-REMS Prototype Cost Summary

Item No.	PART Description	QTY	Unit Price	Prototype Cost	Target Cost
1	SCT-BT (Sensor)	1	$4,545	$4,545	$3,500
2	EB-320 (Phone)	1	$1,800	$1,800	$900
3	(Cabinet)	1	$415	$415	$200
4	(Solar Panel, Reg & Battery)	1	$768	$768	$400
5	(Stand)	1	$250	$250	$100
6	Computer	1	$260	$260	$90
7	Modem	1	$800	$800	$400
8	Sampler	0	$4,400		
9	Misc. bits			$400	$300
10	Labour			$5,000	$1,000
	Factory Cost			$14,238	$6,890
	Margin	50%			
	Selling Price			$28,476	$13,780

6.3. Tasks and Resources

Table 6–2 below summarizes the resources required to finish the development and launch the PV-REMS based product. The major tasks include *Market Survey, Product Development, Pilot Scale Testing, Acquisition of a Marketing Partner, Pilot Production, and Product Launch Review*. Most of the terminology used in the table bears common well known meaning, but there are a few items which require explanation.

The headings include all the normal costs associated with industrial activity. The column "Start Week" is the expected number of weeks into the commercialization project at which the itemized activity can begin. Where major Tasks can be overlapped, that overlap has been taken into account, e.g. item 16 can begin as soon as the "Cost Guidelines", item 8, has been completed.

Labour is calculated at a normalized rate of $500 per day. The actual rates will range between $350 and $700 per day, but $500 is taken as a conservative average. The rate is calculated with break-even overheads included. Supplies, Capital equipment, Travel, etc, is estimated at cost.

The "Days of Effort" are conservatively large for each activity listed and represent actual level of effort as opposed to elapsed time. The overall estimates are likely to be low however, because of unanticipated activities or problems. The tasks are more serialized than would actually occur; this takes into account the fact that very few people are ever focussed on one single project and interferences inevitably occur.

Overall the commercialization of PV-REMS is estimated to cost about $0.5M. There will be some offsetting income, on the order of $140K due to the sale of the pilot production, and it is possible that our marketing partners will contribute licensing or distribution fees. But these latter fees will be offset by a distributor discount structure, usually ranging up to 25-30%.

The bulk of the expenditures, over $213K, is expected to be spent on actual development. This may seem high, but through experience, i.e. learning the hard way, we have found out that even a simple product needs to be tested and documented and tested again. There is usually some small problem which consumes enormous amounts of effort to solve. Even though it seems that the bulk of the development work is done, by virtue of the fact that we have a working prototype, the detail that must be handled is very large.

The next most resource consuming tasks are market related. About $90K worth of effort is required to define the markets, the product and establish relationships with marketing partners. ZENON is very strong technically, but is very limited in terms of direct sales force. Our most successful endeavours have been those where we worked with distributors/dealers who were well known and respected in given markets. It is also true that different distributors might be actively selling the same ZENON product in the same geographic territory, but to different segments of the market.

Item	TASK Activity	Start Week	Days of Effort	Labour at $500/day	Supplies, Travel & Fees	Capital Equipment	Item Totals	Major Task Totals
1	**Market Survey**							
2	Assess gross potential markets	1	10	$5,000			$5,000	
3	Prepare and Issue Questionnaire	3	10	$5,000	$1,000		$6,000	
4	Evaluate Responses	5	5	$2,500			$2,500	
5	Prepare a Product Specification	6	10	$5,000			$5,000	
6	Feature List	8	3	$1,500			$1,500	
7	Operational Scenarios	9	10	$5,000	$2,000		$7,000	
8	Cost Guidelines	11	5	$2,500			$2,500	
9	Prepare Marketing Plan	12	10	$5,000	$200		$5,200	
10	Determine Pricing Structure	14	5	$2,500			$2,500	
11	Define Market Segmentation	15	5	$2,500			$2,500	
12	Assess Offshore Markets	16	10	$5,000			$5,000	
13	Allowance for additional work	18	20	$10,000			$10,000	$54,700
15	**Product Development**							
16	Prepare Detailed Development Plan	12	10	$5,000			$5,000	
17	Allow for Full Time Product Manager	12	30	$15,000			$15,000	
18	Review Spec and List Design Options	14	5	$2,500			$2,500	
19	Prepare Hardware Design	15	5	$2,500			$2,500	
20	PV Power System Requirements	16	2	$1,000			$1,000	
21	Cellular Phone Requirements	16	3	$1,500			$1,500	
22	Computer Requirements	17	2	$1,000			$1,000	
23	Sensor/Measurement Requirements	17	10	$5,000			$5,000	
24	Sampler Requirements	19	2	$1,000			$1,000	
25	Schematics	19	20	$10,000			$10,000	
26	PCB Layouts	23	20	$10,000			$10,000	
27	Mechanical Drawings	27	30	$15,000			$15,000	
28	Operator's Manual - Hardware	33	10	$5,000			$5,000	
29	Prepare Software Design	35	5	$2,500			$2,500	
30	Feature List	36	3	$1,500			$1,500	
31	Effect of Hardware Constraints	37	5	$2,500			$2,500	
32	Flow Charts or Pseudo-code	38	10	$5,000			$5,000	
33	Operator's Manual - Software	40	5	$2,500			$2,500	
34	Verify Cost Targets Met	41	3	$1,500			$1,500	
35	Assess Need for Patent Protection	42	2	$1,000			$1,000	
36	Apply for Patent(s)	42	20	$10,000	$7,000		$17,000	
37	Build Preproduction Prototypes (Qty. 3) 2 for field and 1 for lab testing.							
38	Prepare Detail Drawings	0	15	$7,500			$7,500	
39	Order Components	3	5	$2,500	$10,000		$12,500	
40	Order Sensor Package	4	2	$1,000	$12,000		$13,000	
41	Order Subassemblies	4	5	$2,500	$3,000		$5,500	
42	Complete Assembly of Hardware	5	15	$7,500	$1,000		$8,500	
43	Electrical Functional Testing	8	15	$7,500			$7,500	
44	Update Documentation	11	5	$2,500			$2,500	
45	Code and Test Software	12						
46	Code & Test I/O Words	12	10	$5,000			$5,000	
47	Code & Test Communications	14	10	$5,000			$5,000	
48	Code & Test Procedures	16	10	$5,000			$5,000	
49	Set up Host Computer Procedures	18	15	$7,500		$10,000	$17,500	
50	Perform System Functional Testing	21						
51	Calibrate Sensor Package	21	15	$7,500			$7,500	
52	Verify Correct Data Acquisition	24	5	$2,500			$2,500	
53	Verify Correct Data Transmission	25	3	$1,500			$1,500	
54	Exercise all Procedures	26	5	$2,500			$2,500	
55	Update Documentation	27	3	$1,500	$500		$2,000	$213,500

Item	TASK Activity	Start Week	Days of Effort	Labour at $500/day	Supplies, Travel & Fees	Capital Equipment	Item Totals	Major Task Totals
56	**Pilot Scale Testing (3 mo.)**							
57	Negotiate 2 Test Sites	21	5	$2,500			$2,500	
58	Install at 1st Test Site	22	2	$1,000	$500		$1,500	
59	Install at 2nd Test Site	23	2	$1,000	$500		$1,500	
60	Monitor Data Collection	23	15	$7,500			$7,500	
61	Analyze Data Collected	26	15	$7,500			$7,500	
62	Identify Surrogate Measurements	29	10	$5,000			$5,000	
63	Corelate with MISA Results	31	10	$5,000	$2,000		$7,000	
64	Update Code & Documentation	33	3	$1,500	$500		$2,000	$34,500
66	**Acquire Marketing Partner**							
67	Survey Potential Marketeers	8	20	$10,000	$5,000		$15,000	
68	Select a Short List of Distributors	12	5	$2,500			$2,500	
69	Negotiate Market Specific Agreements	13	30	$15,000	$2,000		$17,000	
70	Issue Production Schedules	19	5	$2,500			$2,500	
71	Train Marketing Partners	20	20	$10,000	$1,000		$11,000	$48,000
73	**Initiate Production**							
74	Prepare Bill of Materials	33	5	$2,500			$2,500	
75	Order Components for Pilot Run	34	3	$1,500	$30,000		$31,500	
76	Prepare Manufacturing Handbook	35	20	$10,000			$10,000	
77	Prepare Test Specification	39	10	$5,000			$5,000	
78	Set up Production Area	41	10	$5,000	$2,000	$15,000	$22,000	
79	Hire and/or Train Production Staff	43	10	$5,000			$5,000	
80	Produce Initial Batch (10 Max)	45	50	$25,000			$25,000	
81	Ship Initial Units	55	2	$1,000			$1,000	
82	Install at End-users	55	10	$5,000	$10,000		$15,000	
83	Allow for Warranty Repairs	57	30	$15,000	$2,000		$17,000	$134,000
85	**Review Product Launch**	57						
86	Assess Distributor Performance	57	5	$2,500			$2,500	
87	Evaluate Margin	58	5	$2,500			$2,500	
88	Review need for Offshore Prod'n	59	5	$2,500			$2,500	$7,500
			Days	Labour	Supplies	Capital	Project	
	Totals		**750**	**$375,000**	**$92,200**	**$25,000**	**$492,200**	

6.4. Preliminary Schedule

It is expected that the commercialization cycle would extend over two years from time of initiation. It could theoretically be compressed to as short a period as nine months, but there again, experience suggests that where other organizations are involved, e.g. distributors, clients, funding agencies, there may be other priorities which inevitably delay the process. The other negative aspect of compressing the development cycle is that there will be more waste, due to late breaking engineering changes and therefore rework and retrofitting of product that has reached the field with problems.

6.5. Benefits

Commercialization of PV-REMS would benefit several parties, provided that a tangible market can be established. These parties include ZENON which would gain sales and profits; ZENON's clients who would save on their effluent monitoring costs[6]; and the Government of Canada who would gain royalties and revenue from taxes from all parties—producers, sellers, and buyers.

[6] There would clearly be two major thrusts in marketing the product, namely labour cost savings associated with automatic monitoring, and from a regulatory point of view the ability to detect spills sooner and therefore reduce pollution.

7. Conclusions

The conclusions one can draw from this project are very direct and simple. Through this project, ZENON has developed a awareness of the economic and technical benefits of photovoltaics, which would not have occurred otherwise. The PV-REMS prototype is a visible manifestation of this awareness, and a new tool in ZENON's kit of pollution fighting hardware. The cellular phone network can be used to simplify, or at least expedite the collection of data from remote sites.

In spite of the challenges that were faced during the project, the essential outcome was successful. ZENON has benefited by the acquisition of new technology, and a new software specialist. EMR has established another PV user and has perhaps helped several other energy and resources industries, if PV-REMS is brought to market.